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Yee

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(54) **OPTICAL FAULT MONITORING**

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(58) **Field of Classification Search** 250/201.1, 250/559.39, 559.4, 559.41–559.43, 559.45, 250/559.46; 356/243.8; 359/15; 235/454, 235/462.06, 462.31
See application file for complete search history.

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(57) **ABSTRACT**

Various embodiments related to monitoring for optical faults in an optical system are disclosed. For example, one disclosed embodiment provides, in an optical system comprising a light source, a light outlet, and an optical element disposed between the light source and the light outlet, a method of monitoring for optical system faults. The method includes detecting, via a light sensor directed toward an interface surface of the optical element closest to the light source, an intensity of light traveling from the interface surface of the optical element to the light sensor, and comparing an intensity of light detected to one or more threshold intensity values. The method further includes identifying an optical system fault condition based on comparing the intensity of light detected to one or more threshold values, and modifying operation of the optical system.

17 Claims, 3 Drawing Sheets

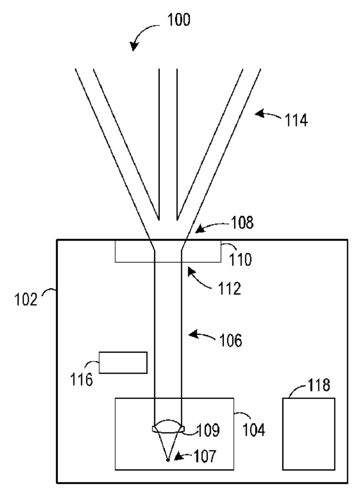

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FIG. 1

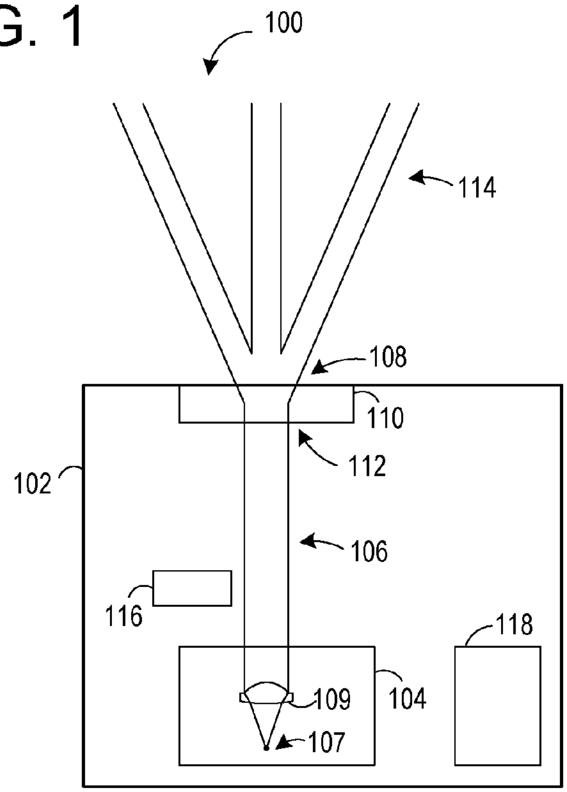

100
114
108
110
112
102
106
116
118
109
104
107

FIG. 2

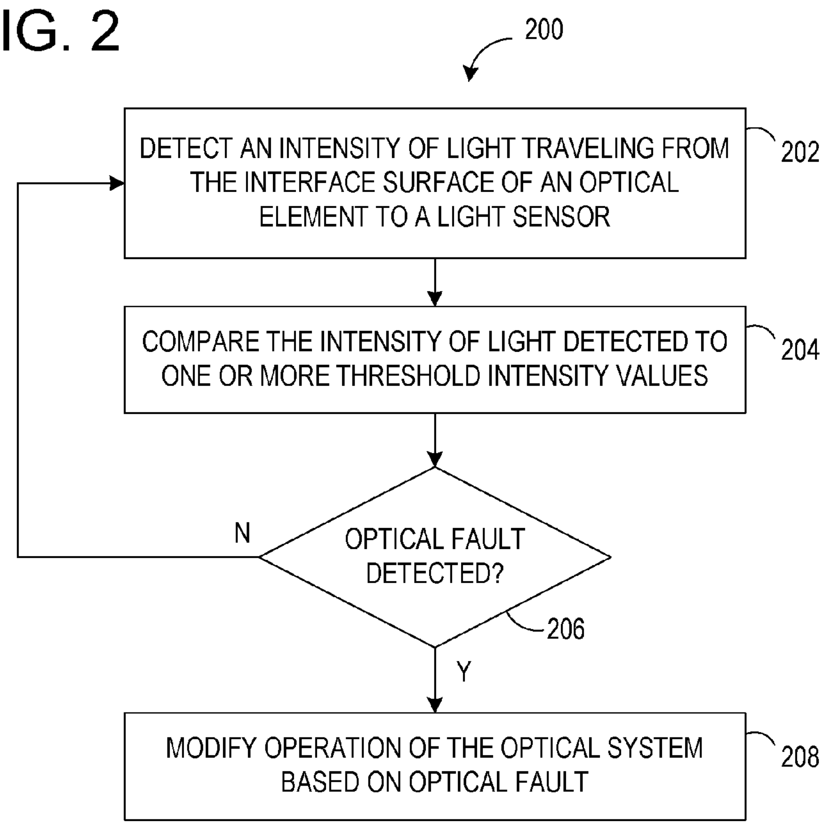

200
DETECT AN INTENSITY OF LIGHT TRAVELING FROM THE INTERFACE SURFACE OF AN OPTICAL ELEMENT TO A LIGHT SENSOR
202
COMPARE THE INTENSITY OF LIGHT DETECTED TO ONE OR MORE THRESHOLD INTENSITY VALUES
204
N
OPTICAL FAULT DETECTED?
206
Y
MODIFY OPERATION OF THE OPTICAL SYSTEM BASED ON OPTICAL FAULT
208

FIG. 3

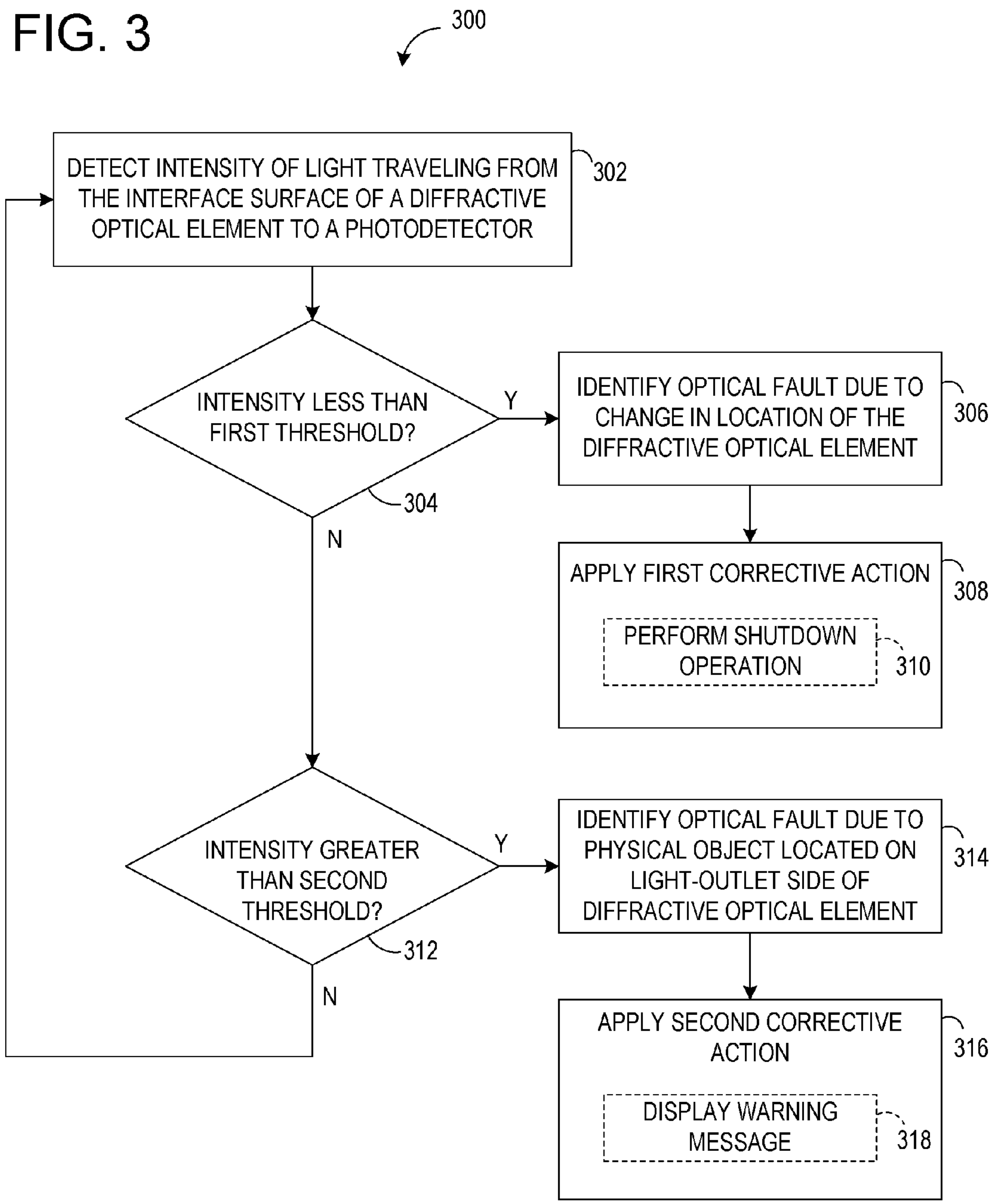
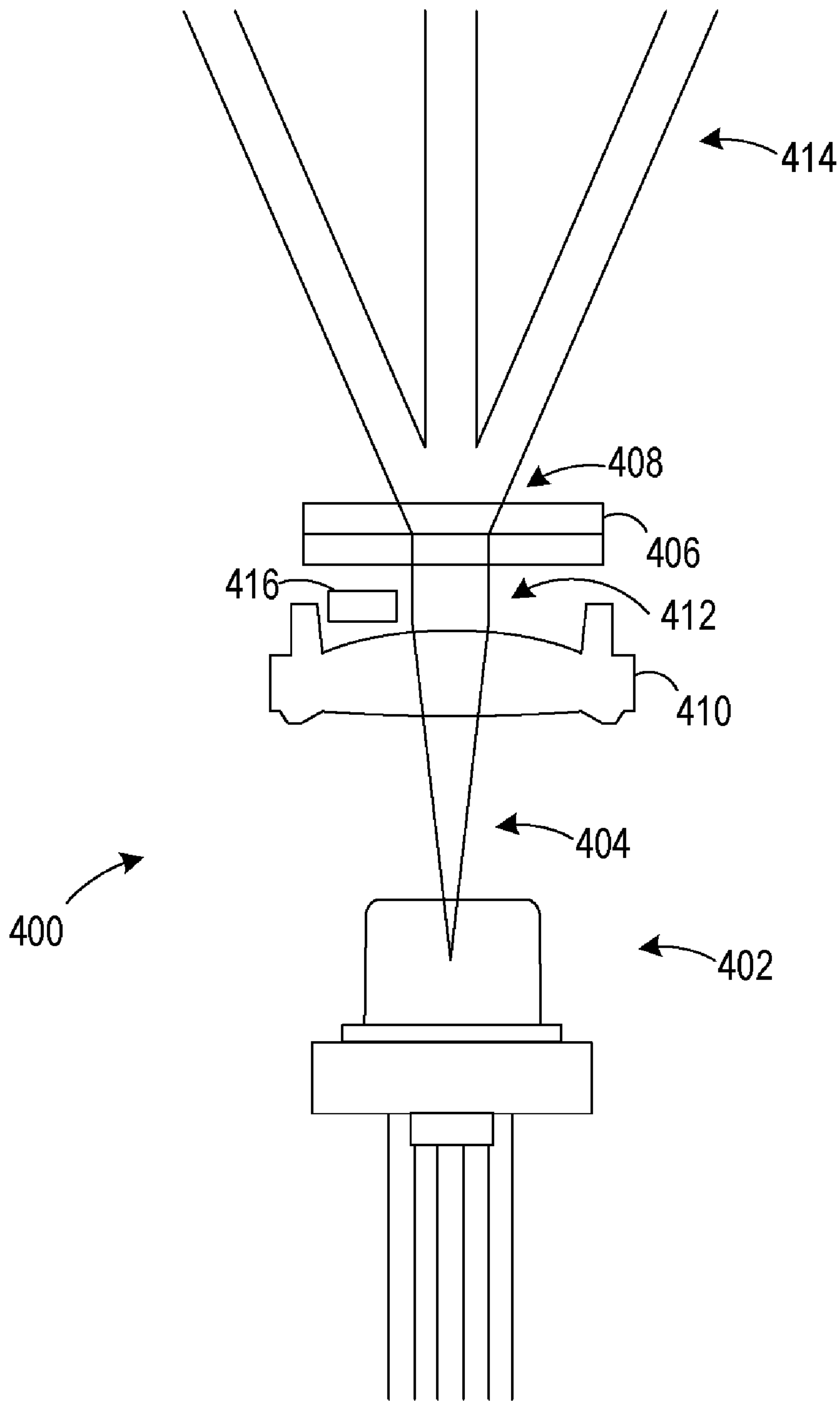

300
DETECT INTENSITY OF LIGHT TRAVELING FROM THE INTERFACE SURFACE OF A DIFFRACTIVE OPTICAL ELEMENT TO A PHOTODETECTOR
302
INTENSITY LESS THAN FIRST THRESHOLD?
304
Y
N
IDENTIFY OPTICAL FAULT DUE TO CHANGE IN LOCATION OF THE DIFFRACTIVE OPTICAL ELEMENT
306
APPLY FIRST CORRECTIVE ACTION
308
PERFORM SHUTDOWN OPERATION
310
INTENSITY GREATER THAN SECOND THRESHOLD?
312
Y
N
IDENTIFY OPTICAL FAULT DUE TO PHYSICAL OBJECT LOCATED ON LIGHT-OUTLET SIDE OF DIFFRACTIVE OPTICAL ELEMENT
314
APPLY SECOND CORRECTIVE ACTION
316
DISPLAY WARNING MESSAGE
318

FIG. 4



OPTICAL FAULT MONITORING

BACKGROUND

Optical projectors and other optical devices may utilize a laser or other relatively bright light source to project an image onto a surface. For example, some depth-sensing cameras may utilize a diffractive optical element to transform light from a laser source to project a structured light pattern on a target in the field of view of an image sensor. Variations in the structured light pattern from an expected pattern that are caused by the distance of the target from the camera may be used to determine a distance of the target from the camera.

Depth-sensing cameras and other optical systems may rely upon the location of DOEs and other optical components to remain constant for proper device performance. Therefore, in the case of a depth-sensing camera, if an optical element becomes misplaced or damaged, the reference structured light image may change compared to that expected by the image processing software. However, such an optical system fault may not be easily discernable by the camera and depth-sensing image processing software. Therefore, various faults may result.

SUMMARY

Accordingly, various embodiments related to optical fault monitoring are disclosed herein. For example, one disclosed embodiment provides, in an optical system comprising a light source, a light outlet, and an optical element disposed between the light source and the light outlet, a method of monitoring for optical system faults. The method includes detecting, via a light sensor directed toward an interface surface of the optical element closest to the light source, an intensity of light traveling from the interface surface of the optical element to the light sensor, and comparing the intensity of light detected to one or more threshold intensity values. The method further includes identifying an optical system fault condition based on comparing the intensity of light detected to one or more threshold values, and modifying operation of the optical system based upon the optical system fault condition.

This Summary is provided to introduce a selection of concepts in a simplified form that are further described below in the Detailed Description. This Summary is not intended to identify key features or essential features of the claimed subject matter, nor is it intended to be used to limit the scope of the claimed subject matter. Furthermore, the claimed subject matter is not limited to implementations that solve any or all disadvantages noted in any part of this disclosure.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** shows a schematic depiction of an example optical system.

FIG. **2** shows a flow diagram of an embodiment of an example method of monitoring for optical system faults.

FIG. **3** shows a flow diagram of another embodiment of an example method of monitoring for optical faults.

FIG. **4** shows a schematic depiction of an example depth-sensing camera.

DETAILED DESCRIPTION

Optical devices such as depth-sensing cameras may utilize a laser, or other such light source, modulated by a diffractive optical element to project a structured light pattern on a target

in the field of view of an image sensor. As such, the distance from the camera to the target (i.e., the depth from the camera to the target) may be determined based on detecting variations in the projected structured light pattern. For example, a variation may be detected if the reference structured light image differs from that expected by the image processing software. However, other sources may cause variations in the projected structured light pattern that are independent of depth detection, and instead result from optical faults in the optical system. Optical faults may include, but are not limited to, damage to and/or contamination of an optical element, changes in positioning of an optical element, physical objects in an optical path of the optical element, and the like. Such optical faults may not be easily discernable by the camera and depth-sensing image processing software, resulting in ambiguity of fault mitigation.

Therefore, the monitoring of faults in such an optical device, as described herein may provide for the detection and determination of optical faults, and enable the application of corrective and/or mitigating actions. FIG. **1** shows an example optical system **100** within an optical device **102**, wherein optical device **102** includes a light source **104** configured to output a beam of light **106**. Examples of suitable light producing elements **107** for use within light source **104** may include, but are not limited to, one or more lasers, laser diodes, light emitting diodes, etc. Further, in some embodiments, light source **104** may include a collimating lens **109** configured to collimate the beam of light **106**.

As depicted, the beam of light **106** exits optical device **102** through a light outlet **108**. Light outlet **108** may be any suitable outlet through which the light may leave the optical device, such as a hole, a filter, a plastic cover, a lens, etc. Optical device **102** further includes an optical element **110** disposed between light source **104** and light outlet **108**. Optical element **110** may be any suitable optical element configured to receive the beam of light **106** on a light-source side of the optical element (i.e., at an interface surface **112**) and to diffract the beam of light **106** to form a structured pattern, as depicted in FIG. **1** at **114**. As an example, in a structured light depth sensor, optical element **110** may comprise a diffracting optical element.

Due to propagation reciprocity symmetry, optical element **110** may be bidirectional. As such, in addition to optical element **110** directing the beam of light **106** from an interface surface **112** toward the light outlet **108** as described above, optical element **110** may also direct light received through the light outlet **108** toward the interface surface **112**. As an example, upon exiting light outlet **108**, beam of light **106** may reflect off of a physical object within the optical path, and this reflected light may then be directed back through light outlet **108** and through optical element **110** toward the interface surface **112**.

As such, optical device **102** further includes a light sensor **116** directed toward interface surface **112** of optical element **110** closest to the light source **104** (i.e., a light-source side of the optical element **110**) so as to detect such light traveling from interface surface **112** toward light sensor **116**. Light sensor **116** may comprise any suitable sensor for detecting an intensity of light traveling from interface surface **112** of optical element **110** to light sensor **116**. Examples include, but are not limited to, photodetectors and image sensors.

Optical device **102** further includes a controller **118** configured to perform various device functions. For example, where the optical device **102** is a structured light depth sensor, the controller **118** may be configured to control the projection of a structured light pattern, and to determine a distance of objects located in front of the depth sensor via an image of the structured light pattern, as described above. Further, controller **118** may be configured to detect an optical fault condition based upon a signal received from the light sensor **116**. Controller **118** may determine an optical fault condition in any suitable manner. For example, controller **118** may monitor an intensity of light received from interface surface **112** as measured by light sensor **116**, and compare the measured intensity of light to one or more threshold intensity values. Controller **118** may be further configured to apply one or more response actions upon detecting an optical fault condition. For example, controller **118** may be further configured to change a power state of optical device **102** if an upper or lower threshold is met (e.g. shut off light source **104**), and/or display a warning message on a display device. Methods of optical fault monitoring are described in more detail hereafter with reference to FIGS. **2**-**4**.

FIG. **2** shows a flow diagram of an embodiment of an example of a method **200** of monitoring for optical system faults in an optical system, wherein the optical system comprises a light source, a light outlet, and an optical element disposed between the light source and the light outlet, as described above. At **202**, method **200** includes detecting an intensity of light traveling from the interface surface of the optical element to the light sensor. As described above, in some embodiments, an interface surface of an optical element may comprise the surface of the optical element closest to the light source. The intensity of the light may be detected via any suitable sensor, including but not limited to a photodetector and/or an image sensor directed toward the interface surface of the optical element closest to the light source.

Next, at **204**, method **200** includes comparing the intensity of light detected to one or more threshold intensity values, and then at **206**, determining if an optical fault condition exists based on this comparison. As will be described in more detail hereafter with reference to FIG. **3**, identifying an optical system fault condition may include determining that the intensity of light detected is less than a threshold value, greater than a threshold value, outside of an operating range of expected values, etc. Examples of optical system fault conditions include, but are not limited to, a change in a location of the optical element within the optical system, a physical object close to or blocking the light outlet, a contamination of the optical element, and other such conditions that may interfere with proper optical system operation.

Continuing with FIG. **2**, if it is determined at **206** that an optical fault is not detected, then method **200** returns to **202**. However, if it is determined at **206** that an optical fault is detected, at **208**, method **200** includes modifying operation of the optical system based upon the optical system fault condition. The operation of the optical system may be modified in any suitable manner depending upon the nature of the optical fault detected. Examples include, but are not limited to, changing a power state of the optical device, performing a corrective action, displaying a warning message on a display device, displaying a message prompting a user to perform an action, etc. The optical system may further determine whether or not the user has performed the action, and the optical system may then further modify operation of the optical system based on this determination.

As an example, in one embodiment, the optical system may determine an optical fault condition indicating presence of a physical object located on a light-outlet side of the optical element and in the optical path of the optical element. The optical system may in response display on a display device a warning message asking the user to remove the physical object. If the optical system determines that the physical object has not been removed, for example after a predetermined time duration, the optical system may further modify operation of the optical system by performing a shutdown operation. Additional examples of optical fault conditions and corrective actions are described hereafter.

FIG. **3** shows a flow diagram of another embodiment of an example method **300** of monitoring for optical faults. Method **300** may be performed, for example, by a structured light depth-sensing camera comprising a light source, a light outlet, and a diffractive optical element disposed between the light source and the light outlet. FIG. **4** shows a schematic depiction of an example embodiment of a depth-sensing camera **400** comprising a light source **402** configured to output a beam of light **404** that is directed through a diffractive optical element **406** toward a light outlet **408**. As a nonlimiting example, light source **402** may comprise a laser diode, and may utilize a lens **410** to collimate the beam of light as indicated at **412**. Diffractive optical element **406** then outputs diffracted light through light outlet **408** as a structured pattern, as indicated at **414**.

Returning to FIG. **3**, at **302** method **300** includes detecting, via a photodetector located on a light-source side of the DOE, an intensity of light traveling from the diffractive optical element. As described above, a diffractive optical element and other optical components may be bidirectional in that in addition to transmitting and diffracting light received from the light source, it may also receive light at the light outlet and transmit the light toward the photodetector. FIG. **4** shows an example photodetector **416** located on the light-source side of diffractive optical element **406**, and configured to measure an intensity of light traveling from the light-source side of diffractive optical element **406** via inherent reflections.

Continuing with FIG. **3**, method **300** next includes comparing the measured intensity of the light to one or more threshold values. Two thresholds are described in more detail as follows, however, it is to be understood that additional and/or other comparisons to additional and/or other threshold values may also be made without departing from the scope of this disclosure. At **304**, method **300** includes determining if the intensity of light is less than a first threshold value. If it is determined that the intensity of light is less than a first threshold value, at **306** method **300** includes identifying an optical fault due to a change in a location of the diffractive optical element. For example, the diffractive optical element may have fallen, become dislodged, broken, etc. such that it is no longer properly located within the optical path, thus reducing the intensity of (unintended but inherent) light reflected from the diffractive optical element interface that reaches the photodetector. In this case, as indicated at **308**, method **300** may include applying a first corrective action. For example, in some specific embodiments, the first corrective may include performing a shutdown operation to the projector or overall depth-sensing camera, as indicated at **310**. It will be understood that the term “shutdown” operation as used herein refers to any operation in which the projected beam of light is shut off, whether or not other device components remain powered.

Continuing with FIG. **2**, if it is determined that the intensity of light is not less than the first threshold value, then method **300** proceeds to **312**, where it is determined if the intensity of light is greater than a second threshold value. If it is determined that the intensity of light is greater than a second threshold value, at **314** method **300** includes identifying an optical fault due to a physical object blocking the projected beam of light. Such a physical object may be proximal to the light outlet such that light exiting the light-outlet is reflected by the physical object, and then returns back through the diffractive optical element toward the photodetector, thus increasing the intensity of light reaching the photodetector, causing the second threshold to be reached. If it is determined that the intensity of light is greater than the second threshold value, then method **300** comprises applying a second corrective action. As an example, the second corrective action may include displaying a warning message on a display device as indicated at **318**. For example, the warning message may indicate to a user that there may be a physical object present in the optical path of the depth-sensing camera interfering with proper operation of the depth-sensing camera and request that the user remove the physical object to continue operation of the depth-sensing camera. It will be understood that any other suitable corrective action may be applied in other embodiments.

In some embodiments, method **300** may further include determining that no response has yet been taken to the warning message, for example, within a predetermined time duration, and performing another corrective action, such as performing a shutdown operation. Then, in some embodiments, the depth-sensing camera may periodically be re-powered to determine whether the object has been removed from the beam path. In some embodiments, after performing a shutdown operation, a response may be detected to the warning message and the optical system may be returned to a normal operating state. In other embodiments, the depth-sensing camera may remain in the shut-down state until re-activated by a user.

Continuing with FIG. **3**, if it is determined at **312** that the intensity of light is not greater than a second threshold value, then method **300** returns to **302**.

As described above, any other additional and/or alternative threshold comparisons may be used to determine other fault conditions without departing from the scope of this disclosure. For example, in some embodiments, method **300** may include determining if the intensity of light is outside of an operating range of accepted values, for example, due to contamination of an optical component (e.g. moisture on the diffractive optical element, etc.). If it is determined that the intensity of light is outside of such an operating range, method **300** may include identifying an optical fault due to degraded performance of the diffractive optical element or other optical element, and applying a third corrective action.

In some embodiments, the above-described optical system and methods may be tied to a computing device. As an example, a depth-sensing camera may be included within a gaming system including a gaming console and a display device. It will be appreciated that the computing devices described herein may be any suitable computing device configured to execute the programs described herein. For example, the computing devices may be a mainframe computer, personal computer, laptop computer, portable data assistant (PDA), computer-enabled wireless telephone, networked computing device, or other suitable computing device, and may be connected to each other via computer networks, such as the Internet. These computing devices typically include a processor and associated volatile and non-volatile memory, and are configured to execute programs stored in non-volatile memory using portions of volatile memory and the processor. As used herein, the term "program" refers to software or firmware components that may be executed by, or utilized by, one or more computing devices described herein, and is meant to encompass individual or groups of executable files, data files, libraries, drivers, scripts, database records, etc. It will be appreciated that computer-readable media may be provided having program instructions stored thereon, which upon execution by a computing device, cause the computing device to execute the methods described above and cause operation of the systems described above.

It should be understood that the embodiments herein are illustrative and not restrictive, since the scope of the invention is defined by the appended claims rather than by the description preceding them, and all changes that fall within metes and bounds of the claims, or equivalence of such metes and bounds thereof are therefore intended to be embraced by the claims.

The invention claimed is:

1. In an optical system comprising a light source, a light outlet, and an optical element disposed between the light source and the light outlet, a method of monitoring for optical system faults, the method comprising:

detecting, via a light sensor directed toward an interface surface of the optical element closest to the light source, an intensity of light traveling from the interface surface of the optical element to the light sensor;

comparing the intensity of light detected to one or more threshold intensity values;

identifying an optical system fault condition based on comparing the intensity of light detected to one or more threshold values; and

modifying operation of the optical system based upon the optical system fault condition, wherein modifying operation of the optical system includes one or more of changing a power state of the optical device and providing a warning message for display on a display device.

2. The method of claim **1**, wherein identifying the optical system fault condition includes determining that the intensity of light detected is less than a threshold value.

3. The method of claim **2**, wherein modifying operation of the optical system includes performing a shutdown operation to the optical system.

4. The method of claim **1**, wherein identifying the optical system fault condition includes determining that the intensity of light detected is greater than a threshold value.

5. The method of claim **1**, further comprising detecting no response to the warning message, and performing a shutdown operation to the optical system.

6. The method of claim **5**, further comprising, after performing the shutdown operation, detecting a response to the warning message and in response, returning the optical system to a normal operating state.

7. An optical device, comprising:

a light source configured to output a beam of light;

a diffractive optical element configured to receive the beam of light on a light-source side of the diffractive optical element and to diffract the beam of light to form a structured pattern;

a photodetector directed toward the light-source side of the diffractive optical element, the photodetector configured to measure an intensity of light traveling from the light-source side of the diffractive optical element; and

a controller configured to detect an optical fault condition by monitoring the intensity of light as measured by the photodetector and comparing the intensity of light to one or more threshold values and apply a response action upon detecting the optical fault condition, wherein the response action includes one or more of changing a power state of the optical device and providing a warning message for display on a display device.

8. The optical device of claim **7**, wherein the controller is further configured to change the power state of the optical device if an upper threshold value is met.

9. The optical device of claim **7**, wherein the controller is further configured to change the power state of the optical device if a lower threshold value is met.

10. The optical device of claim **7**, wherein the light source comprises a laser diode.

11. The optical device of claim **7**, wherein the optical device is a depth-sensing camera.

12. In a depth-sensing camera comprising a light source, a light outlet, and a diffractive optical element disposed between the light source and the light outlet, a method of monitoring for optical faults, the method comprising:

detecting via a photodetector located on a light-source side of the diffractive optical element an intensity of light traveling from the diffractive optical element;

comparing the intensity of light to one or more threshold values;

if the intensity of light is less than a first threshold value, identifying an optical fault due to a change in a location of the diffractive optical element and applying a first corrective action; and

if the intensity of light is greater than a second threshold value, identifying an optical fault due to a physical object located on a light-outlet side of the diffractive optical element, and in an optical path of the diffractive optical element, and applying a second corrective action.

13. The method of claim **12**, further comprising, if the intensity of light is outside of an operating range of accepted values, identifying an optical fault due to degraded performance of the diffractive optical element and applying a third corrective action.

14. The method of claim **12**, wherein applying the first corrective action includes performing a shutdown operation to the depth-sensing camera.

15. The method of claim **12**, wherein applying the second corrective action includes displaying a warning message on a display device.

16. The method of claim **15**, further comprising detecting no response to the warning message within a predetermined time duration, and performing a shutdown operation to the depth-sensing camera.

17. The method of claim **16**, further comprising, upon applying the shutdown operation, detecting a response to the warning message and in response, returning the depth-sensing camera to a normal operating state.

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